Supplementary Materials for

Synchronous Caregiving from Birth to Adulthood Tunes Humans' Social Brain

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This file includes:

Supplementary Text

Preregistration

An earlier version of this study was pre-registered on open science framework website on October 2018. However, as we have enlarged the scope of the study considerably adding additional subject groups and analysis we amended this pre-registration. The annulled pre-registration details and amendments can be viewed using the link: https://osf.io/wra8x/?view_only=31a0013b2a264cf38ca992bdc3cdc594

Controlling for age effects

To address the age differences between groups (see table S11, demographics), we confirmed that dissimilarity levels were unrelated to participants' age. A univariate ANOVA analysis, corrected for age and group showed that the Amygdala, TP and Insular dissimilarity levels of joy-sadness, joy-distress and distress-sadness are not significantly different between subjects (joy-sadness corrected $F(3,75)=2.184$, $p=0.097$;joy-distress $F(3,75)=2.389$, $p=0.075$;sadness-distress $F(3,75)=1.666$, $p=0.182$).

The development of synchrony was found to differ among groups ($F(2,76)=8.873$, $p<0.001$; see figure 2) and post-hoc analysis indicated that levels of synchrony in the FT and KC groups were higher compared to the SC group ($p=0.001$;$p=0.002$ respectively, bonferroni corrected). We examined a corrected model in which participants' age in young adulthood was used as a covariate. Results showed that the significant difference between groups remained when controlling for age ($F(3,75)=6.301$, $p=0.001$). The participant's age was not the source of this variability $F(1,75)=1.127$, $p=0.292$) neither for synchrony levels in young adulthood nor for the averaged synchrony score across time (corrected $F(3,75)=13.006$, $p<0.001$; age at young adulthood corrected $F(1,75)=1.281$, $p=0.261$).

TP laterality effect in RSA

Despite the accumulating evidence for TP role as a key socio-emotional region, and following literature associating TP with language and semantic processing [1], we wanted to explore if TP's involvement may be due to its role in semantic and language processing in

humans, as our task included a semantic component. We thus hypothesized that if the TP effect is of semantic origin it is likely that it will show a left lateralized bias, in line with typical lateralization of language systems.

To tackle this, a separate RM ANOVA analysis for left and right TP, was done, in order to examine if there is a difference in dissimilarity levels. The analysis revealed that there was no significant difference between right and left TP dissimilarity levels ($F_{(1,78)}$=2.27, p=0.13). There was a significant main effect for emotion pairs dissimilarity ($F_{(2,156)}$=4.38,p=0.014, η^2_p=0.053), similar to our bilateral ROI findings (fig. 4). Emotions-laterality interaction was also insignificant ($F_{(2,156)}$=0.541,p=0.58). Therefore, our findings indicate that the TP activation pattern is likely not based on semantic properties of the task, but on its social- emotional properties.

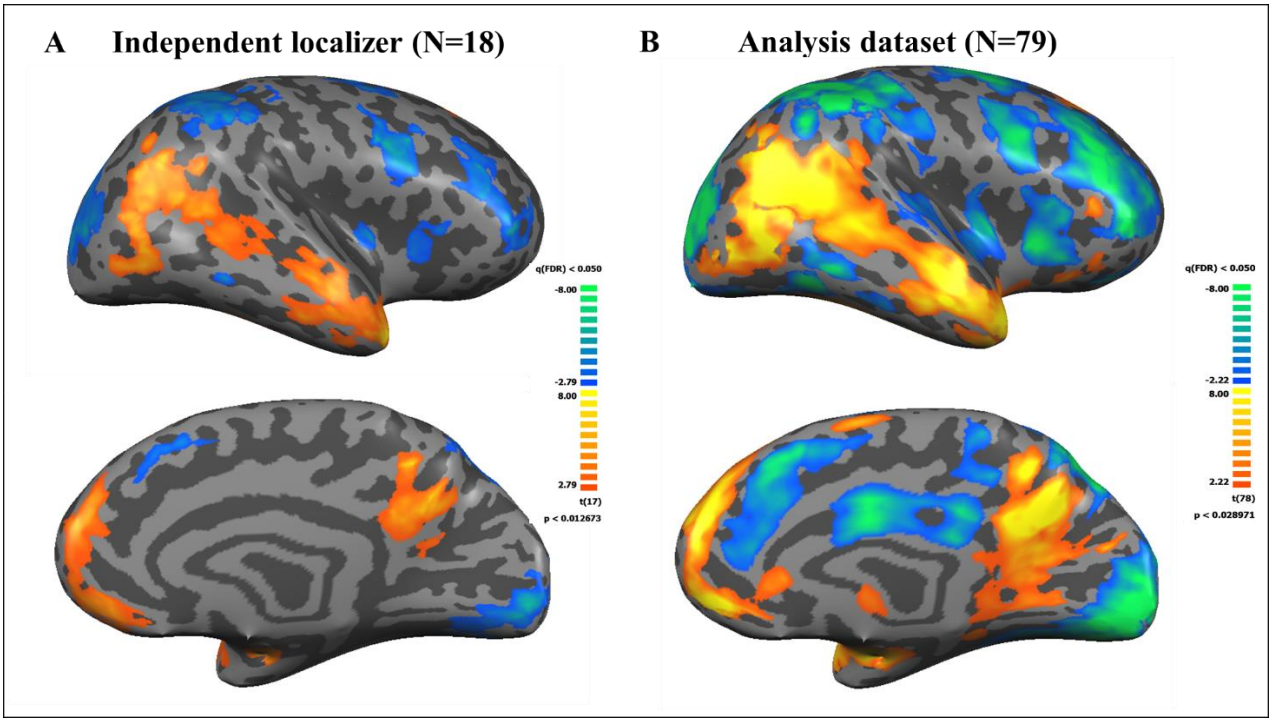

Fig. S1.

Whole brain maps of emotion. **A**: 18 subjects, 6 from each group (FT, KC and SC) were randomly chosen for functional localizer dataset. The presented emotion group map of 18 subjects was used for independent ROI definition, of the contrast emotion>scrambled image, presented on right hemisphere. **B**: same contrast, in the other 79 subjects (analysis dataset) - note the high degree resemblance of activation pattern between A and B. All maps are FDR corrected at $q<0.05$.

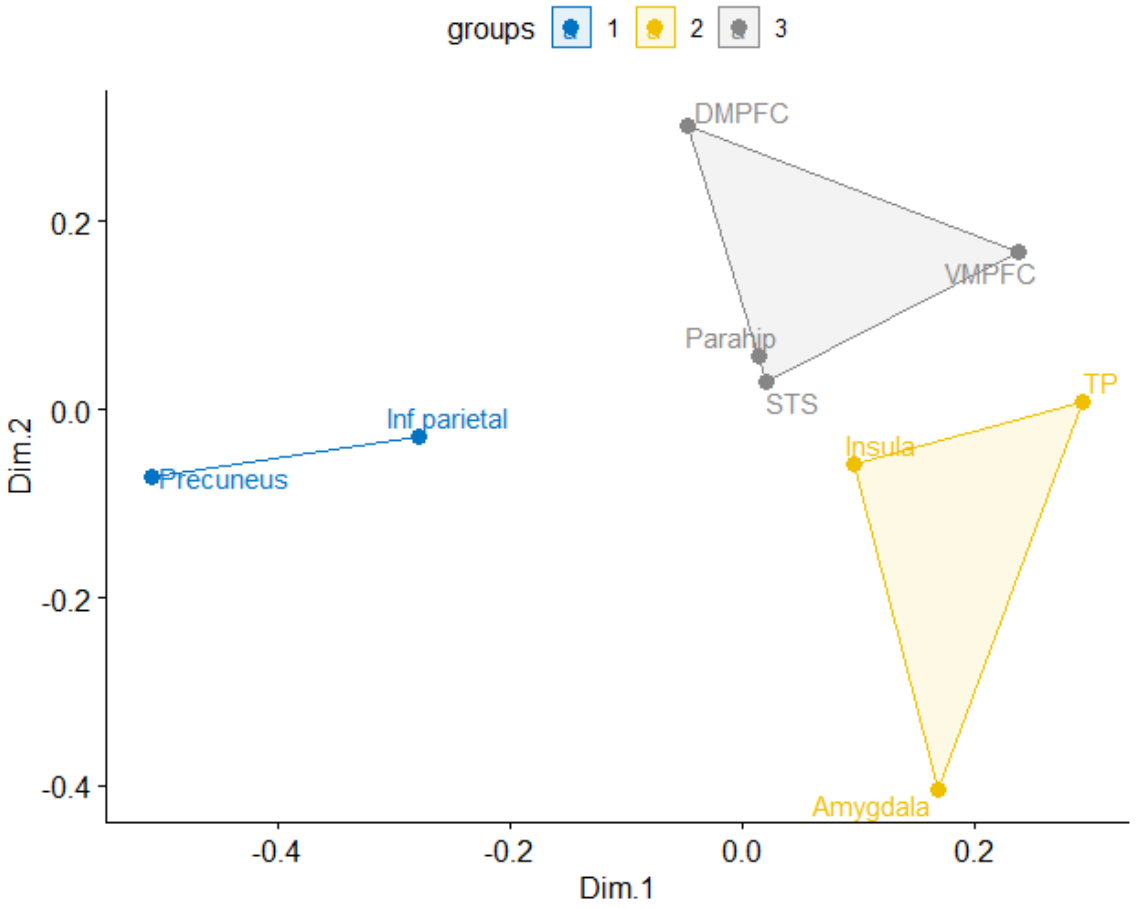

Fig. S2.

Multi-dimensional secondary levels analysis comparing between ROI's emotion specific representational geometries. Using k means clustering (k=3), we identified 3 groups based on the representation pattern of each region. Note the high dissimilarity levels regions – TP, insula and amygdala are clustered together (yellow), while the low dissimilarity regions inferior parietal cortex and precuneus cluster (blue) for a separate cluster.

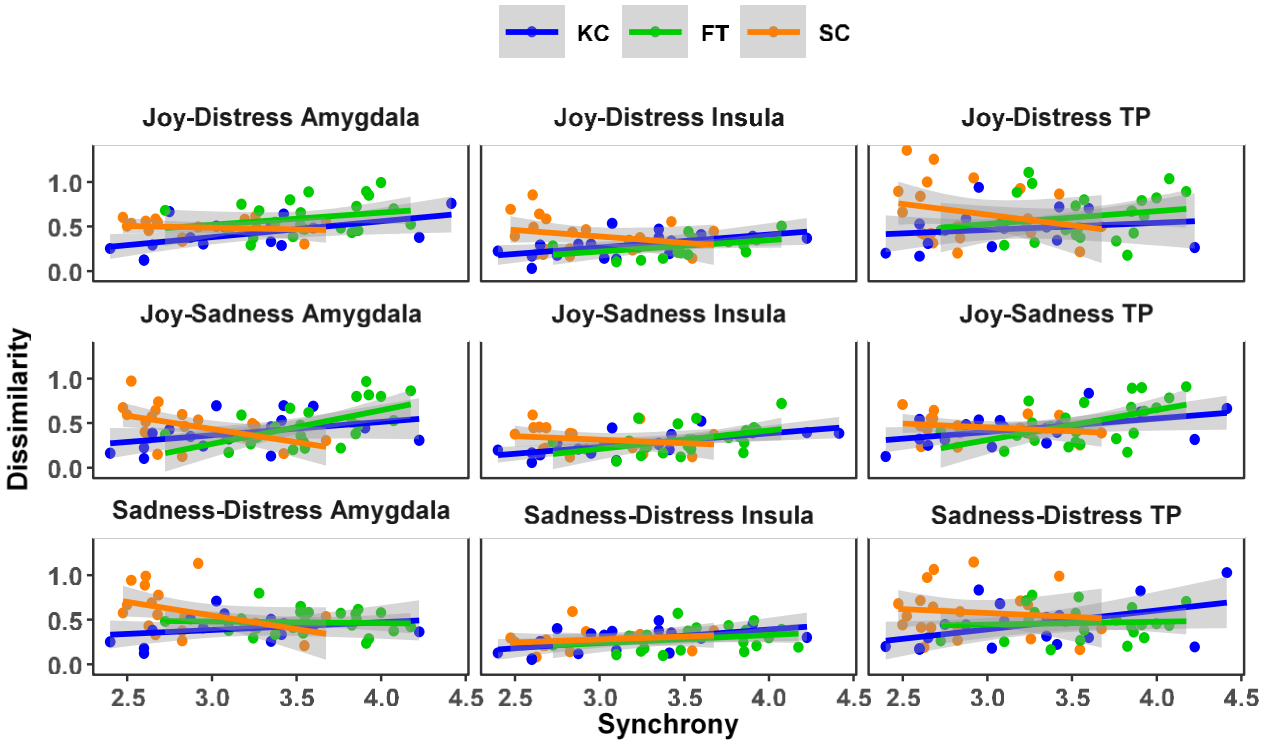

Fig. S3.

Bootstrapped regression for the relationship between behavioral synchrony and dissimilarity levels moderated by birth group

Note:

1. Bootstrapped with 5,000 samples.
2. As can be seen in Table S10., after bootstrap with 5,000 samples, p-values were significant for joy-distress in amygdala and insula for KC, for joy-sadness in amygdala in FT and SC, in insula in FT and KC, and for TP in FT and KC. Lastly, for sadness-distress in amygdala in SC, insula in KC, and for TP in KC

Table S1.

Regions active during emotional empathy

ROI		Mean X	Mean Y	Mean Z	STD X	STD Y	STD Z	K Cluster size	Peak X	Peak Y	Peak Z	t	p
Inferior Parietal cortex	R	44.27	-57.15	18.29	5.26	7.19	5.72	6179	45	-61	25	7.480	0.000001
	L	-44.92	-62.45	20.62	4.83	5.19	6.15	4569	-45	-70	31	7.251	0.000001
Precuneus		-1.35	-51.76	29.2	6.15	5.36	6.56	8327	-6	-55	34	9.471	0
Temporal pole	R	42.6	12.8	-23.02	4.54	4.93	5.33	3570	42	17	-26	9.331	0
	L	-40.87	11.09	-23.19	4.75	4.57	4.52	2983	-42	17	-23	8.080	0
Superior Temporal sulcus	R	50.58	-23.75	-2.42	4.89	19.61	14.61	7649	48	-40	7	6.325	0.000008
	L	-53.12	-20.7	-6.03	6.38	14.66	9.36	4239	-54	-40	1	7.196	0.000001
Amygdala	R	25.4	-11.26	-12.51	5.1	4.55	3.16	2565	30	-4	-14	9.789	0
	L	-25.24	-13.56	-13.02	4.28	5.93	2.93	1796	-33	-7	-14	7.869	0
Parahippocampal gyrus	R	36.62	-36.75	-16.09	2.02	4.54	3.04	541	36	-40	-20	5.399	0.000048
	L	-36.14	-39.44	-16.14	1.61	1.74	2.07	214	-36	-40	-17	5.504	0.000039
VMPFC		-0.76	46.11	-3.71	4.31	5.15	3.8	2685	-9	44	-2	6.651	0.000004
DMPFC		-0.5	52.59	28.39	5.44	3.45	6.11	3223	-3	53	34	5.904	0.000017
Insula	R	38.5	20.5	6	5.77	8.66	5.48	11400	36	17	4	-4.698	0.000207
	L	-38.5	20.5	6	5.77	8.66	5.48	11400	-30	17	4	-5.196	0.000073

Table S2.

Mean dissimilarity levels across ROIs

ROI	*Joy - Distress* Mean	Lower CI	Upper CI
TP	0.594	0.529	0.660
Amygdala	0.551	0.492	0.609
VMPFC	0.434	0.363	0.505
Insula	0.381	0.332	0.429
DMPFC	0.363	0.305	0.420
STS	0.352	0.307	0.396
Parahippocampal gyrus	0.320	0.282	0.357
Inferior Parietal cortex	0.212	0.179	0.245
Precuneus	0.208	0.176	0.241
VC	0.111	0.087	0.135
	Joy - Sadness		
	Mean	Lower CI	Upper CI
TP	0.504	0.446	0.561
Amygdala	0.450	0.401	0.500
VMPFC	0.366	0.303	0.428
Insula	0.356	0.308	0.403
DMPFC	0.321	0.268	0.373
STS	0.294	0.248	0.339
Parahippocampal gyrus	0.275	0.235	0.315
Precuneus	0.174	0.148	0.200
Inferior Parietal cortex	0.143	0.119	0.166
VC	0.088	0.068	0.107
	Sadness-Distress		
	Mean	Lower CI	Upper CI
Amygdala	0.533	0.473	0.592
TP	0.512	0.453	0.572
Insula	0.350	0.305	0.396
VMPFC	0.308	0.256	0.361
STS	0.290	0.252	0.328
Parahippocampal gyrus	0.266	0.231	0.301
DMPFC	0.247	0.211	0.283
Inferior Parietal cortex	0.185	0.149	0.221
Precuneus	0.179	0.155	0.203
VC	0.098	0.077	0.118

Table S3.

Synchrony correlations across child development

		Infancy	Preschool	Adolescence	Adulthood
Infancy	Pearson's r	—			
	p-value	—			
Preschool	Pearson's r	0.584	—		
	p-value	**< .001**	—		
Adolescence	Pearson's r	0.529	0.496	—	
	p-value	**< .001**	**< .001**	—	
Adulthood	Pearson's r	0.492	0.398	0.462	—
	p-value	**< .001**	**< .001**	**< .001**	—

Table S4.

Mean and median percentage of dissimilarity across ROIs

The median dissimilarity levels across all ROIs was 13.901%. Regions were defined as "high dissimilarity" if their median dissimilarity percentage was higher than the general median for all three emotion pairs.

ROI	Emotions	Median % dissimilarity	Mean % dissimilarity
Amygdala	Joy - Sadness	**21.837**	21.706
	Joy - Distress	**27.360**	29.608
	Sadness - Distress	**26.638**	30.041
TP	Joy - Sadness	**23.012**	26.911
	Joy - Distress	**24.830**	30.593
	Sadness - Distress	**26.961**	29.270
Insula	Joy - Sadness	**18.204**	19.064
	Joy - Distress	**18.666**	20.590
	Sadness - Distress	**15.452**	18.789
VMPFC	Joy - Sadness	**15.479**	17.944
	Joy - Distress	**20.004**	23.553
	Sadness - Distress	10.128	15.303
DMPFC	Joy - Sadness	10.154	13.420
	Joy - Distress	**16.002**	17.909
	Sadness - Distress	10.489	11.216
STS	Joy - Sadness	10.311	14.396
	Joy - Distress	12.948	17.237
	Sadness - Distress	12.199	15.322
Parahippocampal gyrus	Joy - Sadness	12.326	14.299
	Joy - Distress	13.570	18.069
	Sadness - Distress	12.085	15.004
Inferior parietal gyrus	Joy - Sadness	5.124	6.856
	Joy - Distress	9.199	11.811
	Sadness - Distress	6.788	11.066
Precuneus	Joy - Sadness	6.152	8.222
	Joy - Distress	9.745	11.364
	Sadness - Distress	6.357	8.971

Table S5.

Bootstrapped regression for the relationship between behavioral synchrony and dissimilarity levels moderated by birth group

	Joy-Distress			**Joy-Sadness**			**Sadness-Distress**		
Predictors	*B*	*CI*	*P*	*B*	*CI*	*p*	*B*	*CI*	*p*
Group FT	-0.11	-0.92 – 0.65	0.755	-0.70	-1.47 – 0.04	0.060	0.36	-0.29 – 1.09	0.274
Group SC	1.19	0.33 – 2.05	**0.009**	1.01	0.49 – 1.58	**0.001**	0.95	-0.03 – 1.86	0.056
Synchrony	0.16	0.02 – 0.29	**0.029**	0.15	0.07 – 0.29	**<0.001**	0.12	-0.04 – 0.30	0.133
Synchrony:Group FT	0.05	-0.18 – 0.29	0.645	0.20	-0.02 – 0.42	0.074	-0.10	-0.33 – 0.09	0.312
Synchrony:Group SC	-0.34	-0.64 – -0.06	**0.020**	-0.32	-0.51 – -0.15	**0.002**	-0.26	-0.57 – 0.07	0.120
R^2 / R^2 adjusted	0.259 / 0.194			0.401 / 0.347			0.213 / 0.143		

Note:

1. Confidence intervals (CI) and p-values are bootstrapped with 5,000 samples.
2. KC was used as a reference group.
3. Bs reflect the unstandardized regression coefficient

Table S6.

Bootstrapped for the slopes of the relationship between maternal behavioral synchrony and dissimilarity levels for each group

	Group	*Est.*	*S.E.*	*t-value*	*CI - 2.5%*	*CI - 97.5%*	*P-value*
Joy - Sadness	FT	0.352	0.074	4.728	0.206	0.498	**0.000**
Joy - Sadness	KC	0.147	0.056	2.628	0.037	0.257	**0.009**
Joy-Sadness	SC	-0.148	0.080	-1.848	-0.304	0.009	0.065
Joy - Distress	FT	0.205	0.099	2.057	0.010	0.400	**0.040**
Joy - Distress	KC	0.156	0.075	2.087	0.009	0.303	**0.037**
Joy - Distress	SC	-0.153	0.105	-1.457	-0.359	0.053	0.145
Sadness - Distress	FT	0.025	0.093	0.269	-0.156	0.206	0.788
Sadness - Distress	KC	0.119	0.083	1.441	-0.043	0.281	0.150
Sadness - Distress	SC	-0.099	0.098	-1.014	-0.291	0.093	0.310

Note: Confidence intervals (CI) and p-values are bootstrapped with 5,000 samples.

Table S7.

Bootstrapped for the slopes of the relationship between maternal behavioral synchrony and dissimilarity levels for each birth group

	Group	*Est.*	*S.E.*	*t-value*	*CI - 2.5%*	*CI - 97.5%*	*P-value*
Joy-Distress Amygdala	FT	0.135	0.097	1.391	-0.055	0.326	0.164
Joy-Distress Amygdala	KC	0.179	0.077	2.324	0.028	0.330	**0.020**
Joy-Distress Amygdala	SC	0.002	0.112	0.016	-0.217	0.220	0.987
Joy-Distress Insula	FT	0.127	0.098	1.291	-0.066	0.319	0.197
Joy-Distress Insula	KC	0.145	0.073	1.978	0.001	0.289	**0.048**
Joy-Distress Insula	SC	-0.146	0.089	-1.645	-0.320	0.028	0.100
Joy-Distress TP	FT	0.145	0.158	0.916	-0.165	0.454	0.360
Joy-Distress TP	KC	0.079	0.153	0.515	-0.222	0.379	0.607
Joy-Distress TP	SC	-0.225	0.165	-1.361	-0.549	0.099	0.174
Joy-Sadness Amygdala	FT	0.377	0.110	3.422	0.161	0.593	**0.001**
Joy-Sadness Amygdala	KC	0.151	0.098	1.536	-0.042	0.343	0.125
Joy-Sadness Amygdala	SC	-0.257	0.116	-2.208	-0.484	-0.029	**0.027**
Joy-Sadness Insula	FT	0.207	0.087	2.374	0.036	0.378	**0.018**
Joy-Sadness Insula	KC	0.152	0.059	2.587	0.037	0.267	**0.010**
Joy-Sadness Insula	SC	-0.089	0.088	-1.017	-0.261	0.083	0.309
Joy-Sadness TP	FT	0.338	0.099	3.413	0.144	0.531	**0.001**
Joy-Sadness TP	KC	0.151	0.075	2.025	0.005	0.297	**0.043**
Joy-Sadness TP	SC	-0.079	0.111	-0.709	-0.296	0.139	0.478
Sadness-Distress Amygdala	FT	-0.018	0.108	-0.165	-0.229	0.194	0.869
Sadness-Distress Amygdala	KC	0.087	0.107	0.818	-0.122	0.296	0.413

Sadness-Distress Amygdala	SC	-0.253	0.120	-2.106	-0.489	-0.018	**0.035**
Sadness-Distress Insula	FT	0.092	0.068	1.355	-0.041	0.225	0.175
Sadness-Distress Insula	KC	0.140	0.059	2.378	0.025	0.255	**0.017**
Sadness-Distress Insula	SC	0.084	0.076	1.113	-0.064	0.232	0.266
Sadness-Distress TP	FT	0.033	0.142	0.231	-0.246	0.312	0.817
Sadness-Distress TP	KC	0.213	0.104	2.043	0.009	0.417	**0.041**
Sadness-Distress TP	SC	-0.053	0.146	-0.362	-0.339	0.233	0.718

Note: Confidence intervals (CI) and p-values are bootstrapped with 5,000 sample

Table S8.

Bootstrapped regression for the relationship between mother and father behavioral synchrony moderated by birth group

Submitted also as a separate file, tableS8.xlsx, due to size

	Joy-Distress Amygdala			**Joy-Distress Insula**			**Joy-Distress TP**			**Joy-Sadness Amygdala**			**Joy-Sadness I**	
Predictors	*B*	*CI*	*p*	*B*	*CI*	*p*	*B*	*CI*	*p*	*B*	*CI*	*p*	*B*	*CI*
FT-KC	0.26	-0.85 – 1.12	0.611	0.03	-0.62 – 0.59	0.932	-0.05	-1.38 – 1.52	0.945	-0.75	-1.81 – 0.28	0.147	-0.18	-1.06 – 0.59
SC-KC	0.77	0.05 – 1.51	**0.035**	1.02	0.21 – 1.92	**0.010**	1.22	-0.23 – 2.70	0.098	1.46	0.63 – 2.41	**0.001**	0.79	0.17 – 1.48
Synchrony	0.18	0.01 – 0.33	**0.040**	0.15	0.07 – 0.27	**0.003**	0.08	-0.15 – 0.43	0.517	0.15	-0.01 – 0.44	0.062	0.15	0.10 – 0.25
Synchrony:FT	-0.04	-0.30 – 0.28	0.783	-0.02	-0.19 – 0.16	0.788	0.04	-0.44 – 0.42	0.852	0.22	-0.12 – 0.52	0.184	0.05	-0.17 – 0.30
Synchrony:SC	-0.22	-0.47 – 0.01	0.057	-0.30	-0.61 – -0.04	**0.019**	-0.35	-0.85 – 0.12	0.145	-0.46	-0.78 – -0.20	**0.001**	-0.24	-0.48 – -0.03
R^2 / R^2 adjusted	0.308 / 0.241			0.250 / 0.175			0.122 / 0.042			0.300 / 0.238			0.221 / 0.148	

Note:

1. Confidence intervals (CI) and p-values are bootstrapped with 5,000 samples.
2. KC was used as a reference group.
3. Bs reflect the unstandardized regression coefficient

Table S9.

Bootstrapped regression for the relationship between mother and father behavioral synchrony moderated by birth group

	Father-infant synchrony		
Predictors	*B*	*CI*	*p*
Group FT	-0.38	-1.97 – 1.20	0.632
Group SC	1.36	0.25 – 2.38	**0.019**
Mother-infant synchrony	0.29	-0.06 – 0.57	0.088
Mother-infant synchrony:group FT	0.18	-0.38 – 0.73	0.512
Mother-infant synchrony:group SC	-0.60	-1.05 – -0.09	**0.022**
R^2 / R^2 adjusted	0.210 / 0.140		

Note:

1. Bootstrapped with 5,000 samples.

Simple slope analysis for the association between mother-infant and father-infant synchrony within each group revealed a significant positive correlation for FT (p<0.05), marginally significant for KC (p=0.09), but a negative correlation for SC (p=0.07).

Table S10.

Bootstrapped regression for the relationship between highest mother or father behavioral synchrony and dissimilarity levels moderated by birth group

	Joy-Sadness			**Joy-Distress**			**Sadness-Distress**		
Predictors	*B*	*CI*	*p*	*B*	*CI*	*p*	*B*	*CI*	*p*
Highest synchrony infancy	0.18	0.13 – 0.28	**0.001**	0.20	0.10 – 0.29	**0.003**	0.18	0.06 – 0.34	**0.006**
group FT [KC]	-0.10	-0.51 – 0.41	0.657	0.24	-0.24 – 0.81	0.363	0.48	0.08 – 0.90	**0.019**
group SC [KC]	0.52	0.18 – 0.86	**0.006**	0.22	-0.30 – 0.60	0.354	0.21	-0.36 – 0.79	0.433
Highest synchrony infancy : group FC	0.03	-0.15 – 0.17	0.718	-0.07	-0.27 – 0.10	0.415	-0.18	-0.35 – -0.03	**0.021**
Highest synchrony infancy : group SC	-0.19	-0.33 – -0.04	**0.018**	-0.03	-0.19 – 0.20	0.735	-0.03	-0.26 – 0.22	0.814
R^2 / R^2 adjusted	0.377 / 0.321			0.298 / 0.235			0.284 / 0.219		

Note:

1. Confidence intervals (CI) and p-values are bootstrapped with 5,000 samples.
2. KC was used as a reference group.
3. Bs reflect the unstandardized regression coefficient

Table S11.

Bootstrapped for the slopes of the relationship between highest mother-father behavioral synchrony and dissimilarity levels moderated by birth group

	Group	*Est.*	*S.E.*	*t-value*	*CI - 2.5%*	*CI - 97.5%*	*P-value*
Joy - Sadness	FT	0.215	0.051	4.211	0.115	0.316	**0.000**
Joy - Sadness	KC	0.186	0.055	3.360	0.078	0.295	**0.001**
Joy - Sadness	SC	-0.004	0.062	-0.063	-0.126	0.118	0.950
Joy - Distress	FT	0.121	0.064	1.876	-0.005	0.247	0.061
Joy - Distress	KC	0.197	0.071	2.795	0.059	0.336	**0.005**
Joy - Distress	SC	0.163	0.078	2.085	0.010	0.316	**0.037**
Sadness-Distress	FT	0.005	0.058	0.087	-0.109	0.119	0.931
Sadness-Distress	KC	0.181	0.076	2.368	0.031	0.330	**0.018**
Sadness-Distress	SC	0.154	0.070	2.190	0.016	0.292	**0.029**

Note: Confidence intervals (CI) and p-values are bootstrapped with 5,000 samples.

Table S12.

Demographics

	KC	**SC**	**FT**	*P-value*
N	35	43	53	
Age (years) ±STD	18.63 ±0.84	18.67±0.94	21.29±2.10	**<0.001**
Sex	51.43% (18) Male; 48.57 (17) Female	55.81% (24) Male; 44.19 (19) Female	45.28% (17) Male; 54.72% (29) Female	0.584
Dominant hand	71.429% (32) R; 22.86% (11) L	74.419% (32) R; 25.59% (11) L	88.67% (47) R; 9.43% (5) L	0.102
Household Income above average (%)	41.18% (14)	54.06% (20)	82.69% (38)	**<0.001**
Maternal level of education	91.18% (31) Academic	74.36% (29) Academic	89.13% (41) Academic	0.080
Paternal level of education	64.71% (22) Academic	69.70% (23) Academic	86.96% (40) Academic	0.051

Table S13.

Subjects excluded from analysis

	KC	SC	FT	Total
Scanned	35	44	58	137
Excluded due to movements	3	4	6	13
Misplaced in scanner	0	2	6	8
Structural abnormality	2	1	0	3
Technical problem with scanner	0	1	1	2
Other	1	2	5	8
Subjects Analyzed (%)	29 (82)	34 (77)	40 (68)	103 (75)

References

1. Wong, C. & Gallate, J. The function of the anterior temporal lobe : A review of the empirical evidence. *Brain Res.* **1449**, 94–116 (2012).